

DØ Run 2b Silicon Tracker Upgrade Executive Summary

The proposed DØ silicon detector has a 6 layer geometry arranged in a barrel design. The detector will be built in two independent half-modules joined at $z=0$. The six layers, numbered 0 through 5, are divided in two radial groups. The inner group, consisting of layers 0 and 1, will have axial readout only. Driven by the stringent constraints on cooling, these layers will be grouped into one mechanical unit called the inner barrel. These layers have a significantly reduced radius relative to the current tracker. Given the tight space constraints, emphasis has been placed on improving the impact parameter resolution. The outer group is comprised of layers 2 through 5. Each outer layer will have axial and stereo readout. The outer layers are important for providing stand-alone silicon tracking with acceptable momentum resolution in the region $1.7 < |\eta| < 2.0$ where DØ has good muon and electron coverage but lacks coverage in the fiber tracker. The outer layers are assembled in a mechanical unit called the outer barrel. The inner barrel is inserted into the outer barrel forming a half-module. A half-module is the basic unit that is installed in the collision hall. While all 6 layers are designed to withstand 15 fb^{-1} of integrated luminosity with adequate margin, separating the inner layers into a separate radial group provides a path for possible replacement of these layers. The outer layers should easily withstand luminosities up to $\sim 25 \text{ fb}^{-1}$. The inner two layers with axial readout will provide an adequate impact parameter resolution for tagging of b-jets. Two layers as close to the interaction point as possible are preferred to efficiently tag b-jets. The remaining space can accommodate at most four axial-stereo layers, which is adequate to do the pattern recognition. Hence our design calls for six layers.

Of paramount importance to the successful construction of the new detector in the less than 3 years available, is a simple modular design with a minimum number of part types. This is one of the reasons that single-sided silicon sensors are used throughout the detector. Only three types of sensors are foreseen: radiation tolerant sensors for layers 0 and 1, with two sizes to best fit the geometrical constraints, and a single sensor size for the four outer layers. All of the sensors are envisioned to have axial traces with intermediate strips. The stereo readout in the outer layers will be accomplished by tilting the sensor slightly with respect to the beam axis.

Figure 1 shows an axial view of the Run 2B silicon tracker. The emphasis is on obtaining improved impact parameter resolution in the $R\text{-}\phi$ plane while maintaining good pattern recognition. The inner two layers have 12-fold crenellated geometry and will be mounted on a carbon fiber lined, carbon foam support structure. Figure 2 shows an axial view of these two inner layers. Layer 0 will have its innermost sensor located at a radius of about 18.6 mm. These

sensors will be two-chip wide, 78.4mm long with 50 micron readout pitch and intermediate strips. The pitch is chosen to obtain the best impact parameter resolution possible using conventional technology. Given the size of the luminous region, 6 sensors in z make up one half-module.

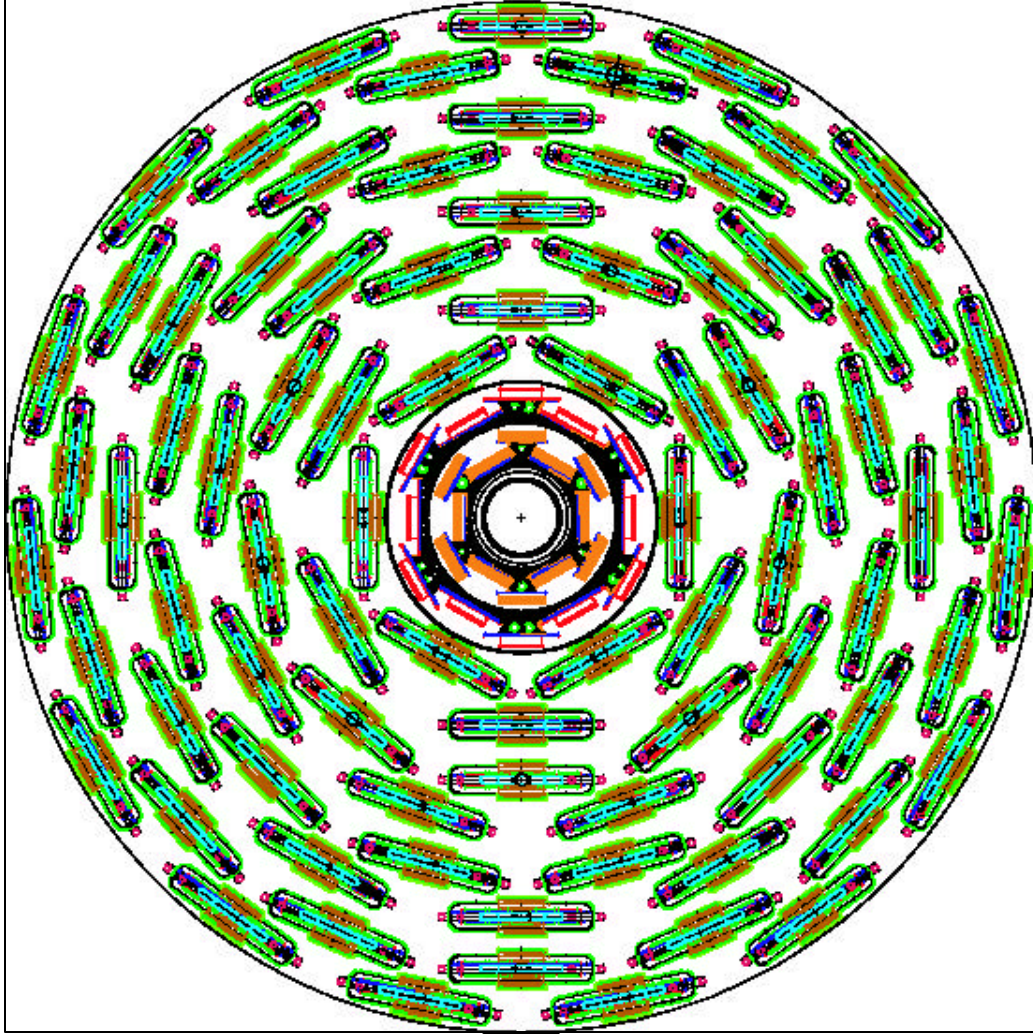


Figure 1 - Axial view of the proposed tracker upgrade. The outer four layers provide both axial and stereo track measurements, while the inner two layers only provide axial track measurements.

Because of the lack of space available and the cooling requirements for the innermost layer, no readout electronics will be mounted on the sensors, i.e. the layer will have 'off-board' electronics. Analog cables will be wirebonded to the sensors, carrying the analog signals to a hybrid where the signals will be digitized and sent to the data acquisition system. Keeping the hybrid mass out of the detector active region also helps in reducing photon conversions. Present CDF experience with noise issues from these cables are a concern but given the requirement that the inner layer has to survive 15 fb^{-1} , there is no alternative to

off-board readout electronics. A major challenge in building the mechanical structure for this layer is ensuring that it provides the cooling capability needed to maintain the silicon at a temperature of -10 degrees C while fitting in all the components necessary and keeping mass to a minimum so that the impact parameter resolution is not degraded. The depletion voltages at the end of the run are expected to be around 600V for the innermost layer. The bias system for the inner layers will be designed to deliver voltages up to 1000V.

Layer 1 will contain 3-chip wide sensors that are 78.4mm long with 58 micron readout pitch, with intermediate strips. The geometry matches the segmentation of Layer 0. Because Layer 1 will also sustain substantial radiation doses, the cooling and bias voltage supply requirements will be the same as for Layer 0. Although the heat load from putting hybrids directly on the sensors is greatly increased (0.5 Watts per readout chip), noise and assembly considerations have led to on-board electronics for all layers except Layer 0.

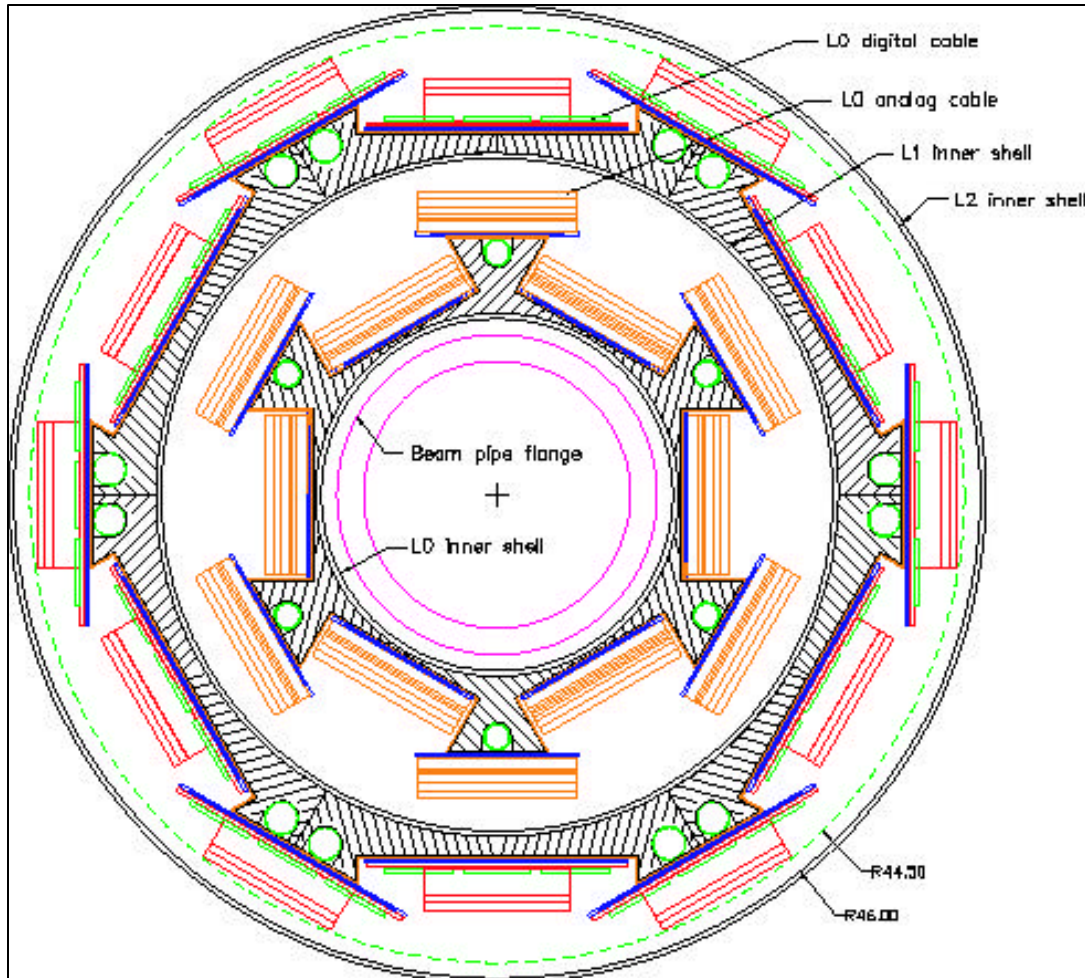


Figure 2 - Axial view of Layers 0 and 1 within the sensor active region. The silicon sensors are mounted on a carbon-fiber lined, carbon foam structure with inboard cooling tubes and then are readout using analog low mass cables which connect to hybrids outside of the active region.

In Layers 2-5 only one type of sensor will be used. The sensors will be 5 chips wide, 100 mm long with 60 micron readout pitch and intermediate strips. This pitch allows for direct bonding between SVX chips and the sensors. Retaining the fine resolution in Layer 5 significantly improves pattern recognition. These layers employ stiff stave support structures. A stave will have carbon fiber sheets mounted on an inner core that will carry the cooling lines. Silicon will be mounted on the carbon fiber sheets; on one side there will be axial readout and on the other small-angle stereo. The stereo angle will be obtained by rotating the sensors. The design allows for a maximum depletion voltage of 300V for these outer layers. Recall that the detector is built in two halves, a north and a south; each stave will thus cover a half-length in z.

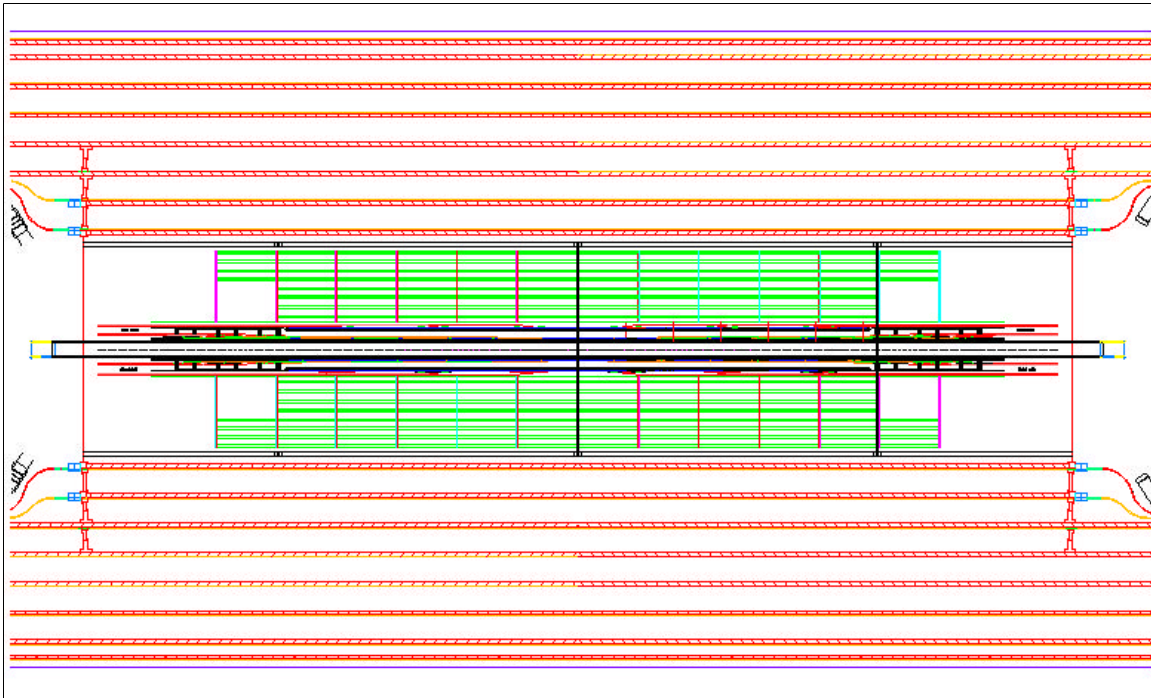


Figure 3 -Plan view of the Run 2B silicon tracker inside of the fiber tracker.

The longitudinal segmentation is driven by the need to match η coverage throughout the detector up to $\eta=2$. For Layer 1 six sensors, each 78.4 mm long, form one half length in z, matching the coverage for L0 which is in the same mechanical structure. For Layers 2 and 3 five sensors, each 100 mm long, will form a stave. Staves consist of six 100 mm long sensors for Layers 4 and 5. Figure 3 shows a plan view of the tracker inside the fiber tracker.

The total number of readout modules in the new system is constrained by the currently available cable plant, which allows for about 940 readouts. The present Run 2A detector has 912 readout modules. This implies that not every one of the 2184 sensors in the detector can be read out separately. By studying deadtime it was determined that for Layers 2 and higher we are able to read out a total of 10 chips. This allows us to use a double-ended hybrid design that reduces the hybrid readout count by a factor of two. A double-ended hybrid services two readout segments at once. Since the sensors are 5-chip wide for the outer layers, the double-ended hybrids will readout 10 chips at a time. The digital signals are carried out of the tracking volume using a digital cable that connects to the hybrid. Layer 1 also employs the double-ended hybrid concept. Since sensors are 3-chip wide in Layer 1, a hybrid will read out 6 chips at a time.

Using double-ended hybrids we've reduced the hybrid count significantly, but not enough to satisfy our cable number constraint. Occupancy studies and confused hit probabilities then determine how best to longitudinally combine (gang) sensors to form a readout segment in z . For the inner two layers every sensor is read out separately. For Layers 2 and 3, there are 5 sensors per half-module in z . The two sensors closest to $z=0$, where the occupancy is highest, are read out individually with one double-ended hybrid. The remaining 3 sensors are connected to another double-ended hybrid. The two sensors at the largest z are wirebonded together and are read out as one unit; the sensor closest to $z=0$ is read out individually. For Layers 4 and 5 we have a total of 6 sensors per half module in z . Here the two innermost sensors are read out individually as in Layers 2 and 3. The outermost 4 sensors are ganged together such that each of 2 sensors is wirebonded together to make one readout unit. This arrangement is depicted in Figure 4. Each stave thus has four hybrids, with each hybrid servicing two readout segments, two for the axial readout and two for the stereo readout. The modules are indicated by the length (in cm) of the two readout segments. A hybrid with 10 cm sensors on each side of the hybrid is called a 10/10 module. Similarly there are 10/20 modules and 20/20 modules. Figure 5 shows the longitudinal segmentation for all layers. An 'S' indicates single sensor readout, and '1/2D' indicates a readout segment serviced by one side of a double-ended hybrid. The colors guide the eye to indicate ganged sensors.

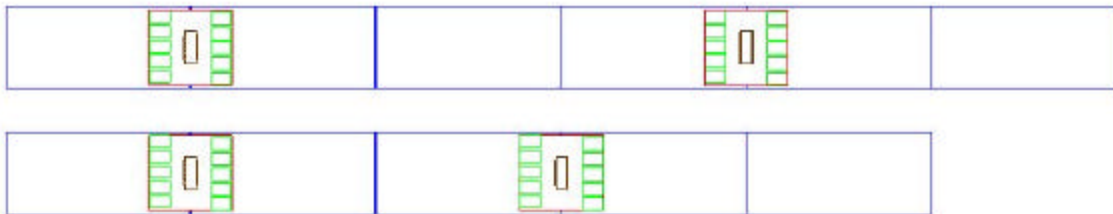


Figure 4 - Readout configuration for outer layer staves. The upper configuration is for layers 4 and 5 and the lower is for layers 2 and 3. Axial readout configuration is shown.

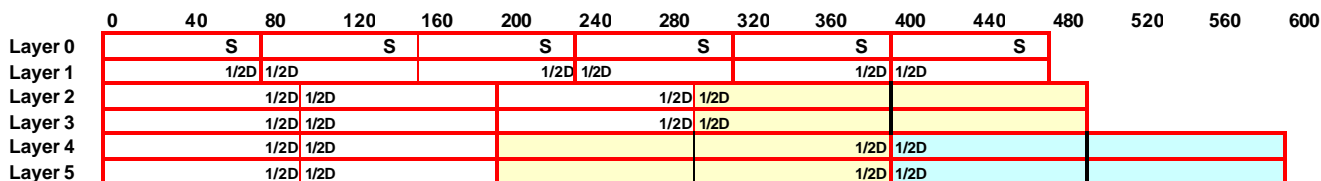


Figure 5 - The longitudinal segmentation of the detector is shown. Here the top row is a ruler showing the length in mm for each of the layers in the detector.

For the stereo side of the stave we have chosen to use the maximum stereo angle possible given the mechanical constraints. This allows us to obtain the best r-z resolution possible. Studies of confused hits, ghost tracks, and occupancy indicate that it is best for the pattern recognition to have the traces of ganged sensors line up, so as to make one long 20 cm trace. For the 10 cm sides of modules the maximum stereo angle is 2.5 degrees while for the 20 cm sides the maximum stereo angle is 1.25 degrees. We then end up with 6 types of modules for the outer layers: 10/10 Axial and Stereo, 10/20 Axial and Stereo, and 20/20 Axial and Stereo.

The decision was made in November 2000 to read out the new silicon system using the SVX4 chip. Both CDF and DØ will use this chip. This chip is based on the SVX3 chip, but will be produced in 0.25 micron technology. This chip is intrinsically radiation hard and is expected to be able to withstand the radiation doses incurred in the innermost layers. In order not to have to redesign the entire DØ data acquisition and trigger system, the SVX4 chip will be read out in SVX2 mode. The SVX2 chip is the readout chip for the Run 2A detector and incurs deadtime on every readout cycle unlike the SVX3 chip that can run in a deadtimeless mode. As the readout chip is a joint project with both CDF and DØ, there is a premium on employing the same hybrid technology so that the design work can be shared. We plan to use ceramic hybrids using beryllia. No pitch adapters will be needed in the DØ design so that the SVX4 chips will be wirebonded directly to the silicon sensors for layers 1-5.

The digital signals will be launched onto a jumper cable from the hybrid through an AVX connector. These flex cables will run on top of the stave to a junction card located at the end of the active region on a bulkhead. There will be one junction card per stave. That is, each junction card will service four hybrids, the two hybrids from the axial readout and the two hybrids from the stereo readout. The junction card is a passive element and simply carries the signals from the digital cable to a twisted-pair cable. The twisted-pair cables run to the adapter cards that are mounted on the face of the calorimeter. The adapter card will interface to the existing data acquisition system. The adapter card has two new functions in Run 2B. First, it will convert 5V lines to 2.5V, necessary for operating the SVX4 chip. The current data acquisition system uses the SVX2

chip, in which the lines are single-ended. The SVX4 chip will be run differentially at 2.5V. The adapter cards will convert the single-ended lines to double-ended lines. From the adapter card downstream, it is anticipated that we can retain the full data acquisition system as is. Some modifications will be needed for the interface boards that pass the voltages to the detector to allow for higher voltages for the biases for the inner layers, but no major modifications are foreseen.

The design parameters are summarized in Table 1. There are a total of 2184 silicon sensors in this design, read out with 888 hybrids containing 7440 SVX4 chips. In layers 2-5 there will be a total of 168 staves, containing 336 readout modules. For comparison, the Run 2A silicon detector has 793K readout channels while the Run 2B one will have 952K readout channels. The Run 2B silicon detector is designed to allow for faster construction due to fewer and simpler parts than the Run 2A device. Comparisons between the detectors show that the major difference between the two detectors is found at the inner and outer radii. By decreasing the radius of the innermost layer from 25.7 mm to 18.6 mm, the impact parameter resolution is cut by a factor of 1.5. Because we are removing the F-disks and the entire cable plant from the Run 2A barrel modules, we are able to utilize this space at larger radii for silicon sensors. The increase from 94.3 mm to 163.6 mm for the outer radius allows us to put in two more layers of tracking necessary for the pattern recognition in the Run 2B environment. With the new detector we will have better stand-alone silicon tracking. A number of factors affect the tracker performance, and consequently the physics performance, of the detector. Among these factors are tracker acceptance, amount of material, resolution, and pattern recognition capabilities. We have optimized our design to the extent possible to obtain a detector that is superior to the Run 2A detector and that will allow us to be well placed for the possibility of discovering new physics.

Table 1 - Design Parameters. There are a total of 2184 sensors and 888 hybrids in this design.

				# Sensors in z	# Sensors Total	Sensor Width	Readout Pitch	# Readout in z	# Chips per Readout	Total Chips	# Hybrids Total
Layer	Nphi	R (mm)									
		Axial	Stereo								
						(mm)	(μ m)				
0A	12	18.55	---	12	72	15.50	50	12	2	144	72
0B	12	24.80	---	12	72	15.50	50	12	2	144	72
1A	12	34.80	---	12	72	24.97	58	12	3	216	36
1B	12	39.00	---	12	72	24.97	58	12	3	216	36
2A	12	53.23	56.33	10	120	41.10	60	8	5	480	48
2B	12	68.93	72.03	10	120	41.10	60	8	5	480	48
3A	18	89.31	86.22	10	180	41.10	60	8	5	720	72
3B	18	103.38	100.28	10	180	41.10	60	8	5	720	72
4A	24	116.91	120.00	12	288	41.10	60	8	5	960	96
4B	24	130.58	133.67	12	288	41.10	60	8	5	960	96
5A	30	150.08	146.99	12	360	41.10	60	8	5	1200	120
5B	30	163.59	160.49	12	360	41.10	60	8	5	1200	120
Total				2184						7440	888